LETTER

Reply to Nott: Assessing biases in speleothem records of flood events

In our reconstruction of extreme rainfall events from the Australian tropics (1), we relied on a method still in its infancy: linking accumulations of sediment trapped within stalagmites to discrete cave flooding events. This sedimentological approach (2, 3) represents an important complement to speleothem-based isotopic methods (4, 5) that expand our understanding of prehistoric tropical cyclone activity.

In his Letter to the Editor (6), Nott notes that identifying mud layers represents a somewhat subjective component of this analysis. In particular, differentiation between thin mud layers and stains on stalagmite carbonate not associated with sediment accumulations is a possible source of error. As we discuss in our report (1) and the associated *Supporting Information*, recognizing flood-derived sediment layers in our stalagmites was complicated by this issue, as well as other factors, including biases associated with preservation of sediment on stalagmite caps and the location of the cuts used to bisect the stalagmites.

To provide the most robust and independent determination possible for identifying flood events, we relied on (*i*) replication of coeval sections of different stalagmites and (*ii*) calibration with historical records of extreme rainfall with a stalagmite formed over the same time period (A.D. 1908–1986). As Nott notes (6), we observed little difference in the temporal trends of extreme rainfall activity over the last two millennia, whether or not we interpreted these stains as cave flooding events.

In addition, we restricted our mud layer analysis to aragonite stalagmites (which comprise the late Holocene portion of the KNI-51 record) because they are faster growing (~1 mm/y) than calcite stalagmites and much more suitable for ^{230}Th dating techniques. Relative to most other studies, the accurate dates well constrained by small errors and the exceptionally high growth rates of KNI-51 stalagmites make this suite of samples unique.

With that said, high-resolution analysis via techniques such as fluorescence, as suggested by Nott (6), may provide new insight into the nature of flood activity in the aragonite speleothems of KNI-51. As Nott notes, abundances of fluorescent compounds such as organic acids would likely be exceptionally diluted in flood waters associated with extreme rainfall events. This would particularly be the case in areas such as the uplands of the eastern Kimberley, which are characterized by thin soils with little organic carbon content, and thus flood waters may contain a different fluorescent signature than traditionally infiltrated fluids.

Rhawn F. Denniston[a,1], Gabriele Villarini[b], Angelique N. Gonzales[a], Victor J. Polyak[c], Caroline C. Ummenhofer[d], Matthew S. Lachniet[e], Alan D. Wanamaker Jr.[f], William F. Humphreys[g], David Woods[h], and John Cugley[i]

[a]*Department of Geology, Cornell College, Mount Vernon, IA 52314;* [b]*IIHR-Hydroscience and Engineering, University of Iowa, Iowa City, IA 52240;* [c]*Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131;* [d]*Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA 02543;* [e]*Department of Geoscience, University of Nevada Las Vegas, NV 89154;* [f]*Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA 50011;* [g]*Western Australia Museum, Welshpool DC, WA 6986, Australia;* [h]*Department of Parks and Wildlife, Broome, WA 6725, Australia; and* [i]*Australian Speleological Federation, Willetton, WA 6155, Australia*

1 Denniston RF, et al. (2015) Extreme rainfall activity in the Australian tropics reflects changes in the El Niño/Southern Oscillation over the last two millennia. *Proc Natl Acad Sci USA* 112(15):4576–4581.
2 Dasgupta S, et al. (2010) Three thousand years of extreme rainfall events recorded in stalagmites from Spring Valley Caverns, Minnesota. *Earth Planet Sci Lett* 300(1-2):46–54.
3 Frappier A, et al. (2014) Two millennia of tropical cyclone-induced mud layers in a northern Yucatan stalagmite reveal multiple overlapping climatic hazards during the Maya Terminal Classic "megadroughts". *Geophys Res Lett* 41(14):5148–5157.
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5 Haig J, Nott J, Reichart G-J (2014) Australian tropical cyclone activity lower than at any time over the past 550–1,500 years. *Nature* 505(7485):667–671.
6 Nott J (2015) Identification of mud flood layers within stalagmites. *Proc Natl Acad Sci USA*, 10.1073/pnas.1512438112.

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[1]To whom correspondence should be addressed. Email: rdenniston@cornellcollege.edu.

Identification of mud flood layers within stalagmites

Denniston et al. (1) provide an important contribution to the prehistoric record of rainfall and tropical cyclones (TCs) in northwest Australia. The authors identify mud layers within limestone stalagmites as evidence of cave flood events and associate these with the passage of TCs. There is little doubt that the prominent thicker layers of mud, some of which occur on the flanks of the stalagmites, were deposited during cave flood events. The methodology used to identify the other reported thinner (<0.5 mm) mud layers, however, is not clearly articulated. Nor is it clear if an objective methodology was used to identify flood layers that may be only several tens of microns thick.

Other studies of flood-deposited mud layers within stalagmites use fluorescence microscopy to identify these features (2, 3), as many of these layers can be very thin (<100 μ). One of these studies (2) used a series of epi-fluorescence photomicrographs of the stalagmite surface, which registered a distinct reduction in fluorescence at the site of a mud layer because of the lack of humic acids within these clays. Humic acids are often incorporated into a layer deposited by drip waters as these waters have percolated through soil above the cave. Floodwaters have reduced amounts of humic acids and fluorescence microscopy can be used to objectively differentiate clays deposited by floodwaters as opposed to those incorporated within cave drip water.

Denniston et al. (1) report numerous mud layers between <0.5 mm and >1 mm thick. Whereas the relatively thick mud layers (>0.5 mm) will be obvious, there could be many other mud layers that are much thinner. In their study, stains (Type 0) that did not appear to contain appreciable mud were recognized and not included in the flood record. However, it is possible that there were also many mud layers that would not have been visible without detailed fluorescence microscopy. Many mud layers identified in other studies (2, 3), for example, were between 10 and 200 μ thick and were layered within annual calcite couplets. Such mud layers, which were included in these flood records, would be difficult to identify without the fluorescence microscopy techniques. Even though Denniston et al. (1) did compare their Type 0 stains with the mud layer record and found no appreciable change in flood behavior over time, it would have been interesting to examine the flood record in their stalagmites using the epi-fluoresecence photomicrograph technique, as many more flood layers may have been identified.

Denniston et al. (1) suggest their flood and TC record supports the view that the medieval period (9th to 15th centuries) was dominated by enhanced La Niña-like conditions across the equatorial South Pacific. Other studies (4, 5) have suggested the opposite, with this period dominated by enhanced El Niño-like conditions. Flood and TC records, such as that presented by Denniston et al. (1), are crucial to help resolve this issue. Using fluorescence microscopy to identify thinner, less obvious flood layers may have revealed a different pattern of floods and TCs.

Jonathan Nott[1]
College of Science, Technology and Engineering, James Cook University, Cairns, QLD 4870, Australia

1 Denniston RF, et al. (2015) Extreme rainfall activity in the Australian tropics reflects changes in the El Niño/Southern Oscillation over the last two millennia. *Proc Natl Acad Sci USA* 112(15):4576–4581.
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Author contributions: J.N. wrote the paper.
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[1]Email: Jonathan.Nott@jcu.edu.au.